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Parametric Study of Powder Mixed EDM and Optimization of MRR & Surface Roughness

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ABSTRACT: In this research work the effect of machining parameters on Surface Roughness and Material Removal Rate (MRR) in a machining operation on Powder Mixed EDM Machine is investigated and the results are optimized by using the Taguchi method. The experimental studies are conducted by keeping various parameters like Current, Voltage, Pulse on time, Duty factor constant and by varying two parameters i.e. Grain size of aluminium powder & Concentration of aluminium powder. An L9 orthogonal array, the signal-to-noise (S/N) ratio are employed to study the performance characteristics in the machining of AISI 1045 steel using Powder mixed EDM machine. The results revealed that grain size of powder and concentration of powder have a great influence on the surface roughness and Material Removal Rate (MRR) in powder mixed EDM.

KEYWORDS: AISI 1045 steel work-piece, copper electrode, concentration of aluminium powder, grain size of aluminium powder, S/N ratio, MRR, Surface Roughness.

1. INTRODUCTION

The development of super tough electrical conductive materials such as carbides, stainless steels, hastalloy, nitralloy, waspalloy, nomonics, etc., arisen the requirement of non-traditional manufacturing processes. These materials are very difficult to machine by conventional methods. Many of these materials find applications in industry where high strength to weight ratio, hardness and heat resisting qualities are required. Electric discharge machining (EDM) is one of the most extensively used non conventional machining processes. It uses thermal energy to machine all electrically conductive materials of any hardness and toughness for applications like manufacturing of dies, automobile components and aerospace parts. Since there is no direct contact between work piece and tool electrode in EDM, machining problems like mechanical stresses, chattering and vibrations dose not arise during machining. In spite of remarkable advantages of the process, disadvantages like poor surface finish and low volumetric material removal limits its use in the industry. To diffuse this problem, EDM in the presence of powder suspended in the dielectric fluid is used and known as powder mixed EDM (PMEDM). It has been experimentally demonstrated that the presence of suspended particle in dielectric fluid significantly increases the surface finish and machining efficiency of EDM process. In PMEDM, a suitable material (aluminium, chromium, copper, silicon carbide, etc.) in powder form is mixed into the dielectric fluid used in EDM. A limited work related to Powder Mixed EDM has been published. **Y.S.Wong et al (1988)**[2] studied the near mirror-finish phenomenon in electrical discharge machining (EDM), when fine powder is introduced into the dielectric fluid and found Particular combinations of powder-mixed dielectric and work piece to produce mirror-finish or glossy machined surfaces. **Y. Uno et al (2001)[3]** suggested that the EDMed surface with metal powder mixed fluid has smaller surface roughness and higher resistance to corrosion because of the diffusion of electrode and/or powder materials into the machined surface. **P. Pecas et al (2003)[4]** used Silicon powder mixed in dielectric fluid and the improvement is assessed through quality surface indicators and process time measurements, over a set of different processing areas. He found the positive influence of the silicon powder in the reduction of the operating time, required to achieve a specific surface quality, and in the decrease of the surface roughness, allowing the generation of mirror-like surfaces. **H.K. Kansal et al (2007)[7]** suggested that Powder mixed electric discharge machining (PMEDM) is one of the recent innovations for the enhancement of capabilities of EDM process. In PMEDM, the electrically conductive powder is mixed in the dielectric of EDM, which reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and workpiece. As a result, the process becomes more stable, thereby, improving the material removal rate (MRR) and surface finish. Moreover, the surface develops high resistance to corrosion and abrasion.

The study demonstrates detailed methodology of the proposed optimization technique which is based on Taguchi method; and ranks the parameters namely grain size of aluminium powder and concentration of aluminium powder through S/N ratio. MRR of a machined work piece along with surface finish of work piece have been optimized.

1.1 Powder Mixed Electro-Discharge Machining (PMEDM)

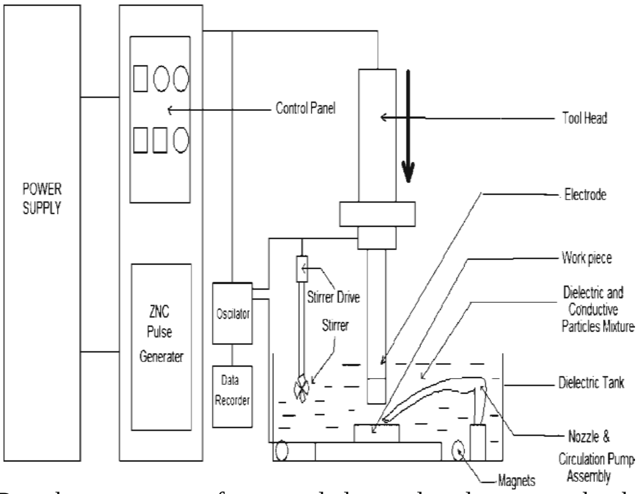
Powder mixed electro-discharge machining (EDM) is being widely used in modern metal working industry for producing complex cavities in dies and moulds which are otherwise difficult to create by conventional machining route. It has been experimentally demonstrated that the presence of suspended particle in dielectric fluid significantly increases the surface finish and machining efficiency of EDM process. Concentration of powder (Aluminium) in the dielectric fluid, Grain Size of powder, pulse on time, duty cycle, and peak current are taken as independent variables on which the machining performance was analyzed in terms of material removal rate (MRR) and surface roughness (SR).

The electrically conductive powder reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and work piece. As a result, the process becomes more stable and thereby improves material removal rate (MRR) and surface finish (SF). The presence of powder increases the gap distance as compared to traditional EDM by at least a factor of two. The enlarged and widened discharge

channel lowers the break down strength of the dielectric fluid and reduces the electrical density on the machining spot. By reducing the spark energy and dispersing the discharges more uniformly throughout the surface, shallow craters are generated.

1.1.1 Methods and Materials

Machining mechanism in PMEDM is slightly different from conventional EDM process. In this process, a suitable material in the powder form is mixed into the dielectric fluid in the machining tank. Machining is performed in this tank and workpiece is placed in it, holding it with the help of a workpiece fixture assembly. The machining tank is filled up with dielectric fluid (kerosene oil) and to avoid particle settling, a stirring system is incorporated. A small dielectric circulation pump is installed for proper circulation of the powder mixed dielectric fluid into the discharge gap. The distance between powder mixed dielectric suction point and nozzle outlet is kept as short as possible (250 mm) in order to ensure the complete suspension of powder in the discharge gap. Two permanent magnets are placed at the bottom of machining tank to separate the debris from the dielectric fluid. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them in conventional EDM.



But the presence of suspended powder decreases the break down strength of the dielectric fluid and reduces the electrical density on the machining spot. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Workpiece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the workpiece surface reaches a point to which the powder had lowered the electric density. The spark gap used to produce spark in PMEDM is twice as much as the gap needed to produce spark in conventional EDM. This way several sparks occur at various locations over the entire surface of the work piece corresponding to the workpiece–tool gap. A schematic diagram of PMEDM is shown in figure.

2. MATERIALS AND METHODS

2.1 Powder Mixed EDM machine (Press Mach-A25)

A Powder Mixed EDM Machine "Press Mach-A25" made by TOOLCRAFT is used to carry out the experimentation.

TABLE - 1
SPECIFICATION OF THE PMEDM MACHINE (PRESS MACH - A25)

Pulse Generator	A25
Working Current	35 amps
Type of Pulse	STD/EQUI-ENERGY
Pulse Time ON/OFF	2-2000 micro sec.
Max. MRR Cu-Steel Gr-Steel	165 mm./min. 190 mm./min.
Working Voltage	35 volts
Surface Finish Cu-Steel	≤ 0.5 microns CLA
Electrode Wear	≤ 0.3 %

2.2 Selection of Machining Tool (Electrode)

The cutting tool selected for present work is copper circular electrode of diameter 12 mm.

2.3 Selection of Work Piece Material

The work piece material used for current work is AISI 1045 Steel.

TABLE – 2
COMPOSITION OF AISI 1045 STEEL

Elements	Weight %
Carbon, C	0.43- 0.5
Manganese, Mn	0.6- 0.9
Phosphorus, P	0.04 max.
Sulphur, S	0.05 max.

2.4 Selection of Conductive Material (Powder)

We used aluminium powder as conductive material (powder) to mix with EDM oil.

TABLE – 3
PROPERTIES OF ALUMINIUM POWDER

Powder	Aluminium
Density	2.70 (g/cm^3)
Thermal Conductivity (at 300K)	237 $W.m^{-1}.K^{-1}$
Electrical Resistivity (at 20˚C)	28.2 nΩ.m
Melting Point	933.47 K
Specific heat capacity (at 25˚C)	24.200 $J.mol^{-1}.K^{-1}$

2.5 Selection of Machining Parameters

The various machining parameters, used in this work, are shown in figure.

TABLE – 4
EXPERIMENTAL SETTINGS

Polarity	Positive
Current	6 Amp.
Voltage	35 Volt
Pulse on time	150 µs.
Duty factor	0.7

2.6 Process Parameters & Levels used in the Experiment

The machining is done on Powder mixed EDM by keeping various parameters like Current, Voltage, Pulse on time, Duty factor constant and by varying two parameters i.e. Grain size of aluminium powder & Concentration of aluminium powder. The parameters and levels used in the experiment are shown in Table-5.

TABLE – 5
PROCESS PARAMETERS AND LEVELS

Levels	Variables	
	Grain Size of Aluminium Powder	**Concentration of Aluminium Powder**
Level 1	Fine (< 150)	2
Level 2	Medium (150 – 225)	4
Level 3	Coarse (225 – 300)	6

2.7 Design Matrix

In the present work there are three levels, two factors. According to Taguchi approach L9 has been selected. So, according to Taguchi L9 array design matrix of variables are formed.

TABLE – 6
DESIGN MATRIX OF VARIABLES

Experiment	Grain/Mesh Size of Aluminium Powder (µm)	Concentration of Aluminium Powder (gm/ltr.)
1	0	0
2	Fine (< 150)	2
3	Fine (< 150)	4
4	Fine (< 150)	6
5	Medium (150 – 225)	2
6	Medium (150 – 225)	4
7	Medium (150 – 225)	6
8	Coarse (225 – 300)	2
9	Coarse (225 – 300)	4
10	Coarse (225 – 300)	6

3. RESULTS AND DISCUSSIONS

2.1 Material Removal Rate (MRR)

The material removal rate is generally described as the volume of metal removed per unit time. To calculate MRR following equation is used to calculate the Material Removal Rate (MRR):

$$MRR(mm^3/min) = \frac{[\text{Initial Weight of workpiece(gm) - Final Weight of workpiece(gm)}]}{\text{Density}(gm/mm^3) \times \text{Machining Time (min)}}$$

The density of the mild steel is taken as 7.69612 x 10^{-3} g/mm^3.

2.2 Surface Roughness (R_a)

Roughness measurement has been done using a portable stylus-type profilometer, Mitutoyo- Surftest SJ- 201P/M. The evaluation length of 2.5 mm is used to measure response R_a value in µm.

2.3 Response Table

Response table for the experimental design matrix is shown in table 7.

TABLE – 7
RESPONSETABLE OF R_a AND MRR

Experiment	Grain /Mesh Size of Aluminium Powder (µm)	Concentration of Aluminium Powder (gm/ltr.)	Work-piece Material Loss(gm.)	Machining Time (Min.)	MRR (mm3/Min.)	Surface Roughness (µm) Length Of Cut =2.5 mm
1	0	0	1.455	9	21.006	5.315
2	Fine (< 150)	2	1.49	9	21.511	5.585
3	Fine (< 150)	4	1.516	9	21.887	5.465
4	Fine (< 150)	6	1.572	9	22.695	5.205
5	Medium 150 – 225	2	1.624	9	23.446	5.4
6	Medium 150 – 225	4	1.685	9	24.327	5.365
7	Medium 150 – 225	6	1.62	9	23.388	5.005
8	Coarse 225 – 300	2	1.287	9	18.581	4.86
9	Coarse 225 – 300	4	1.473	9	21.266	4.66
10	Coarse 225 – 300	6	1.473	9	21.266	4.4

2.4 Analysis of Single Response Stage

The optimal settings and the predicted optimal values for surface roughness and MRR are determined individually by Taguchi's approach. Table VII shows these individual optimal values and its corresponding settings of the process parameters for the specified performance characteristics. It is observed that the grain size of aluminium powder and concentration of aluminium powder have a great influence on MRR and surface roughness.

TABLE – 8
MEANS OF MRR & SURFACE ROUGHNESS AT DIFFERENT LEVELS

Level	Mean Value of R_a		Mean Value of MRR	
	Grain Size	**Concentration**	**Grain Size**	**Concentration**
1	5.418	5.282	22.031	21.179
2	5.257	5.163	23.720	22.493
3	4.640	4.870	20.371	22.450

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TABLE – 9
INDIVIDUAL OPTIMAL VALUES & CORRESPONDING SETTING OF PROCESS PARAMETERS

Performance Characteristic	Optimal Parameter Level	Optimum Level
R_a (μm)	A3-B3	4.4
MRR (mm^3/min)	A2- B2	24.327

TABLE – 10
OPTIMAL VALUES FOR MRR

Grain/Mesh Size	Concentration
21.006	21.006
22.031	21.179
23.72	22.493
20.371	22.45

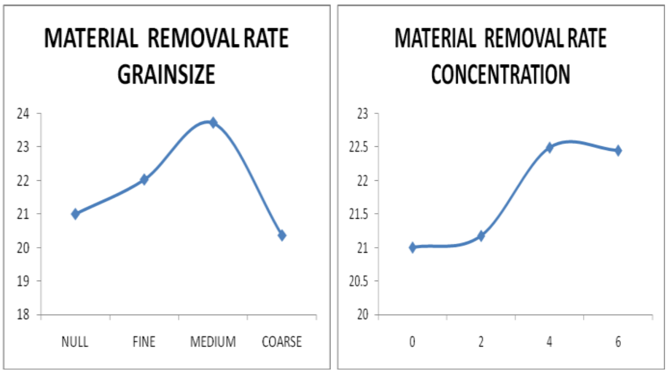

Fig. 1 - RESPONSE GRAPH FOR MRR

ANALYSIS OF PLOT FOR MRR
The data gathered from the experimental work is analysed using single response S/N ratio method to obtain the optimal values of the process parameters. These optimal values for MRR are plotted in two graphs: one based on Grain size of powder and other based on concentration of powder.

Based on Grain Size of Powder
As shown in graph MRR is low when no aluminium powder is mixed with EDM oil. As we mix fine sized aluminium powder in the EDM oil, MRR increases. With the further increase in Grain size of aluminium powder i.e. medium size powder particles, MRR increases further. But as we increase the grain size of aluminium powder further i.e. coarse grain size, MRR decreases. So as a result we get best MRR on Medium sized Powder mixed with EDM oil.

Based on Concentration of Powder
As shown in graph initially when there is no powder mixed with EDM oil, MRR is low. As we mix aluminium powder in the EDM oil in 2 gm/ltr. concentration, MRR increases. As we further increases the concentration of aluminium powder upto 4 gm/ltr., MRR also increases. But as we increase the concentration of aluminium powder further as 6 gm/ltr., MRR reduces. So as a result we get best MRR on concentration 4 gm/ltr. of aluminium Powder mixed with EDM oil.

TABLE – 11
OPTIMAL VALUES FOR SURFACE ROUGHNESS

Grain/Mesh Size	Concentration
5.315	5.315
5.418	5.282
5.257	5.163
4.64	4.87

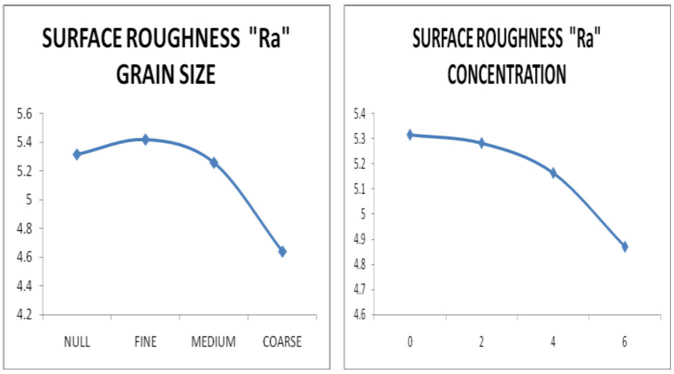

Fig. 2 - RESPONSE GRAPH FOR Ra

ANALYSIS OF PLOT FOR SURFACE ROUGHNESS
The optimal values for Surface Roughness obtained from single response S/N ratio Table are plotted in two graphs: one based on Grain size of powder and other based on concentration of powder.

Based on Grain Size of Powder
As shown in graph Surface Roughness is high when no aluminium powder is mixed with EDM oil. As we mix fine sized aluminium powder in the EDM oil, Surface Roughness increases slightly. With the further increase in Grain size of aluminium powder i.e. medium size powder particles, Surface Roughness starts reducing. As we further increase the grain size of aluminium powder i.e. coarse grain size, Sourface Roughness keeps on decreasing. So as a result we get lowest surface roughness on Coarse sized Aluminium Powder. Lower surface roughness shows the better surface finish. This means that Coarse sized Aluminium Powder gives the best surface finish.

Based on Concentration of Powder
As shown in graph initially when there is no powder mixed with EDM oil, Surface Roughness is high. As we mix aluminium powder in the EDM oil in 2 gm/ltr. Concentration, Surface Roughness decreases slightly. As we further increases the concentration of aluminium powder upto 4 gm/ltr., Surface Roughness reduces further. With the further increase in the concentration of aluminium powder upto 6 gm/ltr., Sourface

Roughness keeps on decreasing. So as a result we get lowest surface roughness on concentration 6 gm/ltr. Of aluminium Powder mixed with EDM oil. Lower surface roughness shows the better surface finish. This means that the best surface finish is achieved on concentration of 6 gm/ltr. Of aluminium Powder mixed with EDM oil.

2.5 Analysis of Multi-Response Stage

The S/N ratio considers both the mean and the variability. In the present work, a multi- response methodology based on Taguchi technique and Utility concept is used for optimizing the multi-responses (Ra and MRR). Taguchi proposed many different possible S/N ratios to obtain the optimum parameters setting. Two of them are selected for the present work. Those are, Smaller the better type S/N ratio for R_a

$$[\eta_1] = -10\log_{10}\left[R_a^2\right];$$

Larger the better S/N ratio for MRR

$$[\eta_2] = -10\log_{10}\left[\frac{1}{MRR^2}\right]$$

From the utility concept, the multi-response S/N ratio of the overall utility value is given by

$$\eta_{obs} = W_1\eta_1 + W_2\eta_2$$

Where W_1 & W_2 are the weights assigned to the R_a and MRR. Assignment of weights to the performance characteristics are based on experience of engineers, customer's requirements and their priorities. In the present work equal importance is given for both Ra and MRR. Therefore W_1 & W_2 = 0.5.

The optimal combination of process parameters for simultaneous optimization of Surface roughness (R_a) and material removal rate (MRR) is obtained by the mean values of the multi-response S/N ratio of the overall utility value are shown in Table 12.

TABLE – 12

DESIGN MATRIX WITH MULTI-RESPONSE S/N RATIO

S. No.	Grain/Mesh Size Of Aluminium Powder (µm)	Concentration Of Aluminium Powder (gm/ltr.)	Surface Roughness (µm)	η_1 for Ra	MRR (mm3/min.)	η_2 for MRR	η_{obs}
1	0	0	5.315	-14.51	21.006	26.447	5.969
2	Fine (< 150)	2	5.585	-14.94	21.511	26.653	5.857
3	Fine (< 150)	4	5.465	-14.751	21.887	26.804	6.027
4	Fine (< 150)	6	5.205	-14.328	22.695	27.118	6.395
5	Medium 150 – 225	2	5.4	-14.647	23.446	27.41	6.382
6	Medium 150 – 225	4	5.365	-14.591	24.327	27.722	6.566
7	Medium 150 – 225	6	5.005	-13.988	23.388	27.380	6.696
8	Coarse 225 – 300	2	4.86	-13.732	18.581	25.381	5.825
9	Coarse 225 – 300	4	4.66	-13.368	21.266	26.554	6.593
10	Coarse 225 – 300	6	4.4	-12.869	21.266	26.554	6.843

TABLE – 13

MEAN VALUES OF η_{obs} AT DIFFERENT LEVELS

Levels	Mean Value of η_{obs} for Process Parameters	
	Grain Size	Concentration
Level 1	6.093	6.021
Level 2	6.548	6.395
Level 3	6.420	6.645

TABLE – 14

INDIVIDUAL OPTIMAL VALUES AND ITS CORRESPONDING SETTINGS OF PROCESS PARAMETERS

Performance Characteristics	Optimum Parameter Level	Optimum Level
η_{obs}	A2-B3	6.696

TABLE – 15

OPTIMAL VALUES FOR MRR & SURFACE ROUGHNESS

Grain Size	Concentration
5.969	5.969
6.093	6.021
6.548	6.395
6.42	6.645

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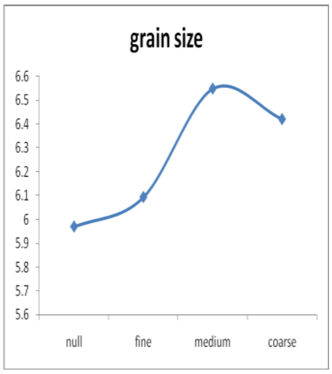

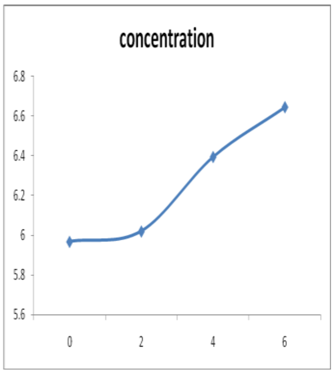

Fig. 3 – MULTI-RESPONSE S/N RATIO GRAPH

INTERPRETATION OF PLOTS

A set of experiments are performed on AISI 1045 Steel Work pieces by using copper electrode in aluminium powder mixed EDM. The data obtained from experiments is optimized using S/N ratio optimization method. Multi-response table has been developed and the optimum values are plotted in the form of graph. The plots show the variation of individual response with the variation in parameters i.e. Grain Size of aluminium powder and Concentration of aluminium powder. In the plots, the x-axis indicates the value of each process parameter at different levels and y-axis indicates the response value. As there are two process parameters, so there are two graphs: one based on Grain size of powder and other based on concentration of powder.

Based on Grain Size of Powder

This graph is a plot between the process parameter i.e. Grain size of aluminium powder on x-axis and the optimum values obtained from Multi-response table on y-axis. This graph gives the combined result for MRR and Surface Roughness. Initially when there is no powder mixed with EDM oil, the optimum value plotted on y-axis is low. As we mix fine sized aluminium powder in the EDM oil, the optimum value on y-axis increases. With the increase in Grain size of aluminium powder i.e. medium size powder particles, the optimum value on y-axis increases further. As we further increase the grain size of aluminium powder i.e. coarse grain size, the optimum value on y-axis reduces. So we get the best result on medium sized Aluminium Powder. On medium sized aluminium powder mixed with EDM oil we get the optimum value for MRR and Surface Finishing.

Based on Concentration of Powder

This graph is a plot between the Concentration of aluminium powder on x-axis and the optimum values obtained from Multi-response table on y-axis. This graph shows the combined result for MRR and Surface Roughness. Initially when no powder is mixed with EDM oil, the optimum value plotted on y-axis is low. As we mix aluminium powder in the EDM oil in concentration of 2 gm./ltr., the optimum value on y-axis increases. With the increase in concentration of aluminium powder i.e. at 4 gm./ltr., the optimum value on y-axis increases further. As we further increase the concentration of aluminium powder upto 6 gm./ltr., the optimum value on y-axis keeps on increasing. So as a result optimum value of MRR and Surface finish is achieved at a concentration of 6 gm./ltr. Of aluminium powder mixed with EDM oil.

4. CONCLUSION

A set of experiments are performed on AISI 1045 steel work pieces by using copper electrode in aluminium powder mixed EDM. The experimental studies are conducted by keeping various parameters like Current, Voltage, Pulse on time, Duty factor constant and by varying two parameters i.e. Grain size of aluminium powder & Concentration of aluminium powder. Mixing of Aluminium powder in Di-electric fluid ensures improved MRR and surface finishing. Based on the results obtained, the following conclusions have been drawn:

- The analysis of the experimental observations highlights that Grain size of aluminium powder and concentration of aluminium powder mixed with EDM oil have a great influence on MRR and Surface finish.
- Too low and too high concentration of aluminium powder in EDM oil reduces MRR of AISI 1045 Steel.
- Too low and too high Grain size of aluminium powder in EDM oil reduces MRR of AISI 1045 Steel.
- As the concentration of aluminium powder in EDM oil increases, surface roughness starts decreasing and keeps on decreasing. So as a result we get lowest surface roughness on concentration 6 gm/ltr. of aluminium Powder mixed with EDM oil. Lower surface roughness shows the better surface finish. This means that the best surface finish is achieved on concentration of 6 gm/ltr. of aluminium Powder mixed with EDM oil.
- As the Grain Size of aluminium powder in EDM oil increases, surface roughness starts decreasing and keeps on decreasing. So as a result we get lowest surface roughness on coarse sized Aluminium Powder. Lower surface roughness shows the better surface finish. This means that coarse sized Aluminium Powder gives the best surface finish.
- If we consider MRR and Surface roughness equally important then too low and too high Grain size of aluminium powder in EDM oil gives lower MRR and lower Surface finish on AISI 1045 Steel. On medium sized aluminium powder mixed with EDM oil we get the best MRR and Surface finish.
- If we consider MRR and Surface roughness equally important then with the increase in concentration of aluminium powder MRR and surface finish of AISI 1045 Steel increases. And at concentration of 6 gm./ltr. we get the best MRR and Surface finish.

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